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Analysis of occupation time of vehicles at urban unsignalized intersections in non-lane-based mixed traffic conditions

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Abstract In India, traffic flow on roads is highly mixed in nature with wide variations in the static and dynamic characteristics of vehicles. At unsignalized intersections, vehicles generally do not follow lane discipline and ignore the rules of priority. Drivers generally become more aggressive and tend to cross the uncontrolled intersections without considering the conflicting traffic. All these conditions cause a very complex traffic situation at unsignalized intersections which have a great impact on the capacity and performance of traffic intersections. A new method called additive conflict flow (ACF) method is suitable to determine the capacity of unsignalized intersections in non-lane-based mixed traffic conditions as prevailing in India. Occupation time is the key parameter for ACF method, which is defined as the time spent by a vehicle in the conflict area at the intersection. Data for this study were collected at two three-legged unsignalized intersections (one is uncontrolled and other one is semicontrolled) in Mangalore city, India using video-graphic technique during peak periods on three consecutive week days. The occupation time of vehicles at these intersections were studied and compared. The data on conflicting traffic volume and occupation time by each subject vehicle at the conflict area were extracted from the videos using image processing software. The subject vehicles were divided into three categories: two wheelers, cars, and auto-rickshaws. Mathematical relationships were developed to relate the occupation time of different categories of vehicles with the conflicting flow of vehicles for various movements at both the intersections. It was found that occupation time increases with the increasing conflicting traffic and observed to be higher at the uncontrolled intersection compared to the semicontrolled intersection. The segregated turning movements and the presence of mini roundabout at the semicontrolled intersection reduces the conflicts of vehicular movements, which ultimately reduces the occupation time. The proposed methodology will be useful to determine the occupation time for various movements at unsignalized intersections. The models developed in the study can be used by practitioners and traffic engineers to estimate the capacity of unsignalized intersections in non-lane-based discipline and mixed traffic conditions.

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1 Introduction

In developing countries, traffic is characterized by a wide mix of vehicle types that differ considerably in their dimensions and performance capabilities. Traffic rules (e.g., give way or lane discipline) are completely ignored in most of these countries. Vehicles can occupy any available lateral position on the road space. Unsignalized intersections perform very efficiently if the total conflicting volume is not very high. For example, at the intersection of a major street and minor street, if the traffic to and from the minor street is low then the intersection works reasonably well irrespective of the traffic volume on the major street. If, however, conflicting movements have significant volumes, then unsignalized intersections become inefficient, causing large delays to the minor movements. This is when signalization becomes imperative. All these conditions result in a very complex traffic situation which has a great impact on the capacity and performance of traffic intersections. Uncontrolled intersections in developing countries are treated as first-in-first-out (FIFO) intersections since none of the traffic streams possess the absolute priority of driving at intersections and generally vehicles approach the intersection alternatively one after another from different streams.

Capacity at two-way stop-controlled (TWSC) intersections is generally analyzed either by regression method or gap-acceptance method. Gap-acceptance method is the widely used method in most of the countries in their own capacity manual. However, in earlier studies it was reported that the gap-acceptance method has a few drawbacks. The gap-acceptance method cannot be applicable to the traffic streams which do not comply with the rules of priority such as forced merging or polite behavior of priority drivers. The gap-acceptance theory fails when pedestrians/cyclists share the space of intersection [1–3]. Therefore, Glue [1] developed a new method called additive conflict flow (ACF), which was modified later by Wu [2]. The key parameter of the ACF technique is the occupation time. Occupation time (t_o) is the time taken by the subject vehicle to clear the conflicting area. Conflict area is an important parameter of an intersection since more number of conflict points occur at this place of intersection which may lead to accidents. If the subject vehicle travels to the other approach without meeting any conflicting vehicle, the occupation time is measured from the moment when it crosses the stop line until it completely enters its destination approach. The flow which creates conflicts with subject vehicle is known as conflicting flow. The occupation time is the summation of service delay (delay at stop line) and time spent in the conflict area till it enters the destination approach. The overall objective of this research work is to analyze the occupation time of vehicles with the conflicting flow of vehicles at unsignalized intersections with the following specific objectives:

- To develop mathematical relations for occupation time of vehicles with the conflicting flow of traffic at an uncontrolled intersection and a semicontrolled intersection.
- To compare the occupation time observed at an uncontrolled and a semicontrolled intersections.
- To develop a mathematical model for estimating occupation time of vehicles at an uncontrolled intersection and a semicontrolled intersection under mixed traffic conditions.

The rest of the paper is structured as follows. Section 2 reviews the previous work done on delay, conflicting flow, gap acceptance, and capacity. Sections 3 and 4 present the data collection and data extraction processes, respectively. Section 5 presents a comparison between uncontrolled and semicontrolled intersections. Section 6 states mathematical relations for occupation time of vehicles for each vehicle type and turning movement at both intersections, followed by the conclusion section.

2 Review of literature

Kyte et al. [4] conducted an empirical study on delay and capacity of the minor approach of two-way stop-controlled intersections and found that service delay mainly depends on the volume of conflicting approaches. Raghavachari et al. [5] developed a simulation model to study the interaction between pedestrian and vehicles in terms of delay at an urban uncontrolled intersection in mixed traffic conditions. Al-Omari and Benekohal [6] framed a methodology to estimate delays at under-saturated two-way stop-controlled intersections. Empirical models were developed to determine service delay as a function of conflicting traffic volume. Troutbeck [7] developed relationships to estimate the capacity and delay for minor street vehicles by using the concept of limited priority at situations where minor stream vehicles forced their entry into a major stream. Bonneson and Fitts [8] described a methodology to predict delay to major street through vehicles due to left turning activity at TWSC intersections. This delay occurred when the demand of major street left turn exceeds the available storage area and blocks the adjacent through lane. Chandra et al. [9] developed a service delay model based on microscopic analysis of delay data in mixed traffic conditions. The mathematical relations were developed for service delays to vehicles based on types and priority movements at uncontrolled intersections. The presence of heavy vehicles in the conflicting traffic was found to have higher impact on the service delay. Chandra and Ashalatha [10] developed a simulation model to study the service delay experienced by the priority movements for different types of vehicles at TWSC intersections in mixed traffic under varying composition of conflicting traffic. It was found that service delay experienced by a priority movement increases when conflicting traffic stream was of mixed type.

Sangole et al. [11] used neuro-fuzzy technique to model the gap-acceptance behavior of right turning two wheelers (TWs) at three-legged intersections in India. The variables such as size of lag/gap (in seconds), age of the driver, conflict vehicle type, occupancy were considered in the study. This study found that TWs could accept a very little gap ($\sim$1.03 s), and the maximum rejected gap was $\sim$9.4 s. Pawar and Patil [12] analyzed temporal and spatial gaps at four-legged partially controlled intersections in India. They estimated the gaps using Raff's method, logit method, lag method, Ashworth Method, and Maximum likelihood Method. The values of temporal critical gap by different methods were found to vary between 2.8 to 3.9 s and spatial critical gap values varied from 31.8 to 36 m. Kanagaraj et al. [13, 14] developed different type of merging models (probabilistic) such as normal, forced, group, and vehicle cover merging models. Factors such as types of lead, lag and subject vehicles, speeds of lead and lag vehicles, longitudinal and lateral gaps between vehicles, waiting time and traffic volume in the main road are considered in these models. The models were calibrated and validated by the maximum likelihood approach using field data collected from a T intersection in Chennai city, India. TWs are more likely to accept a gap compared to auto-rickshaws. If the lead vehicle type is car or auto-rickshaw, the subject vehicle driver is less likely to accept the gap compared to TW as a lead vehicle.

Wu [1] used a new method to calculate the capacity based on the ACF method. Capacity was calculated by considering the interactions between conflict streams and occupation time of each vehicle of the stream occuping the conflict area. Brilon and Wu [3] applied ACF method to find the capacity of TWSC intersections by considering different conflict groups. The major advantage of the new model is that the capacity for any stream can be determined as a function of traffic volumes of other streams. In addition, Wu [15] presented a comprehensive validation of the ACF method and the Highway Capacity Manual (HCM) model for intersections with single-lane approaches. With regard to the total intersection capacity, the modified stream-based HCM model is consistent to the ACF method and other studies. The ACF model and the modified HCM model produce similar capacity results in normal traffic flow conditions. Birlon and Miltner [16] calculated capacities of TWSC intersections using conflict technique. They compared the capacity values observed at the intersection with the capacities observed by Kyte's method and found that due to lack of large number of observations, both have uncertainty of their own kind. To assess the quality of the conflict technique method, a comparison was also made with the conventional gap-acceptance method, both methods showing a rather good correspondence.

Prasetijo [17] found that the ACF method was better in defining the real capacity and service time of each stream of approaches using the value of headway departure. The author determined the capacity of unsignalized intersections in mixed traffic using both the ACF method and IHCM procedure and compared the results of the two methods. Li et al. [18] used a conflict technique to develop capacity models for TWSC, AWSC, and uncontrolled intersections in mixed traffic conditions. The capacities obtained by proposed models match well with the observed capacities as well as with the capacities obtained by conventional methods. The results indicated that pedestrians and bicycle movements have a significant influence on the capacities of vehicular movements. Prasetijo et al. [19] used the occupation time and approaching time of vehicles to calculate the capacity of vehicular movements for each conflict group with flare and without flare intersections under mixed traffic conditions. A comparison was made between the conflict method and the HCM 2000 method. The relationship was obtained between the occupation time and the critical gap.

Most of the studies mentioned above were conducted under homogeneous traffic condition for priority intersections. In India, at uncontrolled intersections no traffic streams possess the absolute priority of driving and vehicles enter the intersection alternatively one after another from different streams. There are limited studies, however, focused on occupation time of vehicles and conflicting flow in mixed traffic. Hence, the present study focuses on analysis of occupation time of vehicles and conflicting flow at unsignalized intersections in non-lane-based mixed traffic conditions.

3 Data collection

In order to study and analyze the occupation time experienced by vehicles, traffic data were collected at two T-intersections in Mangalore city. Intersection A is an uncontrolled intersection which has a four-lane divided major road with width of 7.0 m in each direction and a two-lane undivided minor road of width 7.0 m. Intersection B is a semicontrolled intersection where the major left turning is segregated to 3.5 m width by a physical barrier. It has a four-lane divided major road of width 7.0 m in each direction and a four-lane divided minor road of width 7.0 m in each direction. At this intersection, a mini roundabout is used to reduce the conflicting points. The layout of the two intersections is shown in Figs. 1 and 2. The intersection sites are in urban area with no effect of upstream junctions, on-street parking, and bus stops. It was observed that the queue formation happens rarely on the minor street approach. Traffic data were collected using video graphic technique on three consecutive weekdays for about two hours in each intersection. Video cameras were mounted on vantage points to continuously capture the moving traffic on all approaches of the intersection. The peak hour is determined for both the intersections, which is 9 am to 10 am in the morning. The recorded videos were

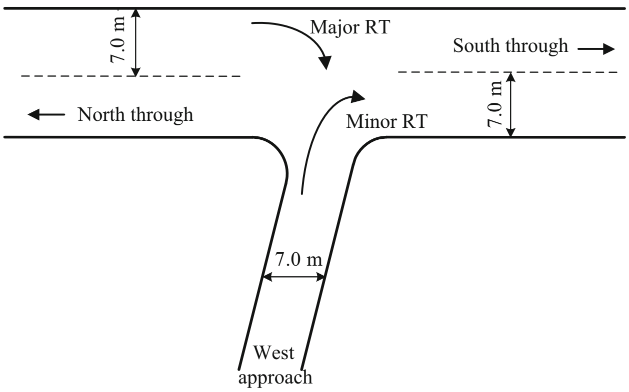


Fig. 1 Layout of Intersection A

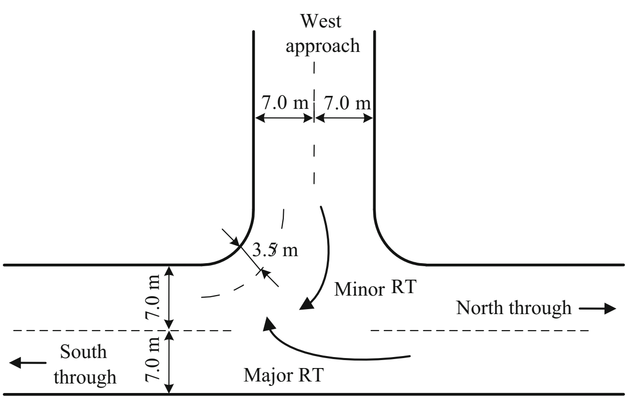


Fig. 2 Layout of Intersection B

played in an image processing (IRFANVIEW 3.99) software to get the occupation time experienced by each subject vehicle and the corresponding conflicting volume (both crossing and merging types of conflicts were considered) for each movement during peak hour. The vehicles on subject approach were classified into five types such as TWs, cars, auto-rickshaws (e.g., three-wheelers), heavy vehicles (HVs), and light commercial vehicles (LCVs).

The computation of occupation time requires the identification of reference lines at each approach of the intersection where the subject vehicles come to stop. In mixed traffic flow, vehicles generally do not respect the stop line and have a tendency to stop very close to the conflicting area. From the preliminary study, it was observed that 70 %–80 % of drivers do not respect the stop line at each approach of the intersection. Conflict area is formed by joining the stop lines (reference lines) of all approaches of the intersection where the vehicles actually stopped. The conflict area was marked as a rectangular area on the screen using an image processing software (Figs. 3 and 4). The turning traffic volumes and traffic composition entering each approach of the intersections are given in Tables 1 and 2.

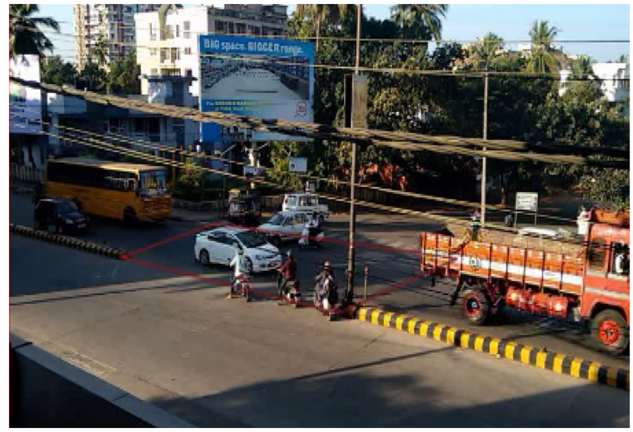


Fig. 3 Uncontrolled Intersection A

Fig. 4 Semicontrolled Intersection B

4 Data extraction

The data on occupation time experienced by vehicles were extracted using microscopic analysis [4]. Let t_a denote the time of arrival of the subject vehicle at the conflict area, t_d the time of departure of the subject vehicle from the conflict area, i the number of conflicting vehicles observed for the subject vehicle including the passage of conflicting vehicle just after departure of the subject vehicle, and t_i the time of arrival of the ith conflicting vehicle at the conflict area. The conflicting flow rate (r_{cf}) of the subject vehicle is defined as the number of conflicting vehicles observed divided by the observation time:

$$r_{cf} = \frac{i}{t_i - t_a}. \tag{1}$$

Note that this definition is different from the standard approach of estimating flow rates, in which averages are reported only for some fixed time period, generally 15 min or 1 h [9].

Occupation time (t_o) can be measured by

Table 1 Traffic composition at Intersection A (unit: veh/h)

Movement type	Total entry volume	TW	Car/jeep	Auto-rickshaw	HV	LCV
Major towards north (straight)	1256	525	211	329	163	28
Minor RT	332	186	57	89		
Minor LT	284	155	32	93		4
Major LT	202	126	35	41		
Major RT	404	266	40	82		10
Major towards south (straight)	1945	1083	260	452	24	26

RT stands for right turn, and *LT* stands for left turn

Table 2 Traffic composition at Intersection B (unit: veh/h)

Movement Type	Total entry volume	TW	Car/jeep	Auto-rickshaws	HV	LCV
Major towards north (straight)	1080	612	249	208	2	9
Minor RT	563	231	151	139	37	5
Minor LT	1203	515	290	265	133	0
Major LT	676	253	210	144	69	0
Major RT	1427	633	353	260	166	15
Major towards south (straight)	650	294	200	147	9	0

$$t_o = t_d - t_a. \tag{2}$$

The above method gives an instantaneous conflicting flow rate for the subject vehicle waiting for a sufficient gap to enter into the conflict area. It is more appropriate for mixed-type conditions where the frequency of occurrence of instantaneous flow is much larger than the average flow due to grouping of vehicles while discharging.

The data were extracted especially for two types of movements such as mino RT and major RT at the intersection under study. These turning vehicles experience more delay and also, need more occupation time compared to remaining movements.

5 Comparison of occupation time at uncontrolled and semicontrolled intersections

Figure 5 illustrates the comparison of average occupation time of all vehicular movements at both the intersections. It was observed that the occupation time of north through movements for semicontrolled intersection (B) is much higher compared to uncontrolled intersection (A). Due to a mini roundabout at the middle of the intersection, north through movements are conflicting with major RT and minor RT vehicles which increases the occupation time of north through vehicles. South through vehicles have the lowest occupation times at both the intersections. When comparing the occupation time at both the intersections, Intersection B has higher values. This is believed to be due to the presence

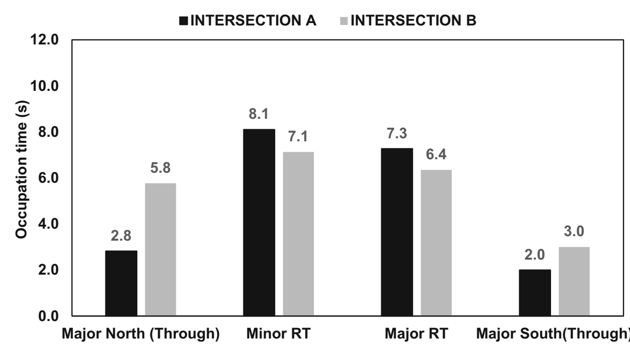
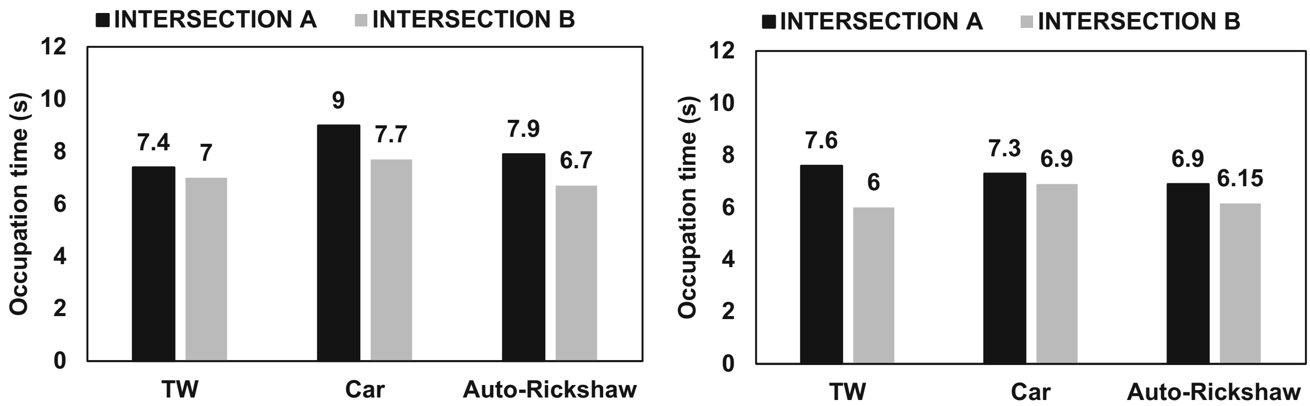


Fig. 5 Comparison of occupation time at Intersections A and B based on turning movements

of mini roundabout and partial control which increases the occupation time of south through movements.

Minor RT vehicles have higher occupation time compared to other vehicular movements. This is because the minor RT vehicles have to wait at the stop line for a longer time to enter the intersection since they have less priority. Less occupation time was observed at Intersection B compared to Intersection A due to lower volume and less number of conflicting points. Major RT vehicles at Intersection B experience less occupation time even though they have higher volumes compared to Intersection A. This may be due to the presence of mini roundabout which reduces the number of conflict points.

Figure 6a shows the comparison of occupation time of vehicles at both the intersections based on vehicle type for major RT. It was seen that all types of vehicles of major RT at intersection A generally has higher occupation time compared



(a) Major RT **(b)** Minor RT

Fig. 6 Comparison of occupation time based on vehicle types

to those at intersection B. The presence of mini roundabout reduces the conflict points at intersection B. A less value of occupation time is observed for TWs at intersection B, which is about 6 s. The presence of higher proportion of TWs among major RT vehicles reduces the occupation time since TWs have higher maneuver ability and smaller size. Auto-rickshaws have less occupation time at Intersection A among major vehicles. The significant proportion of auto-rickshaws with aggressive behavior and poorer queue discipline of drivers reduces the occupation time.

Figure 6b shows the comparison of occupation time of vehicles at both intersections based on vehicle type for minor RT. In both the intersections, cars are having higher occupation time since their proportion is higher particularly at Intersection B (27 %). This is because cars have to wait for sufficient gap at the reference line to enter into the intersection since they have less priority. A less value of occupation time is observed for TWs at intersection A, which is about 7.4 s. This may be due to the presence of higher proportion of TWs among minor RT vehicles. Auto-rickshaws have less occupation time at Intersection B. The aggressive behavior and poorer queue discipline of drivers reduce the occupation time. Heavy vehicles were not observed in Intersection A in the case of major RT and minor RT vehicles and hence it is not shown in Fig. 6.

6 Mathematical relations for occupation time of vehicles

The occupation time was analyzed for three types of subject vehicles such as TW, Car, and Auto-rickshaw and for two types of movements such as minor RT and major RT at both the intersections. Mathematical relations were developed relating the occupation time (t_o) and conflicting traffic volume (V_{CT}) for each subject vehicle with two types of movements (minor RT, major RT) using the statistical software SPSS.

Figures 7 and 8 show the occupation time of vehicles based on type and turning movement at intersections A and B, respectively. The data points showed an exponential trend and the mathematical equations fitted through the data points for each type of vehicle at intersections A and B are given in Tables 3 and 4, respectively. The goodness of fit of the model was evaluated by coefficient of determination (R^2) value and it is seen that all models are statistically significant. The earlier study [4] on modeling delays for homogeneous traffic shows a linear relationship with the data collected from four intersections in Pacific Northwest. A conflicting traffic volume range of 183–1100 veh/h was used to develop this relationship. Chandra et al. [9] found that service delay follows a linear relationship with conflicting traffic up to a conflicting traffic of 0.20 veh/s, after that an exponential trend was followed. They also concluded that the Kyte's linear model overestimates the service delay for higher conflicting traffic flow (above 0.20 veh/s). This may be caused by the reduction in the number of available gaps because of higher rate of conflicting traffic and hence, there is a significant increase in occupation time of low priority movements. Such linear models will not be suitable for high traffic volume existing in mixed traffic and non-lane-disciplined movements which leads to clustering of traffic.

Also, it was observed from the graphs that the occupation time increases with an increase in conflicting flow. When the conflicting traffic is very high, the available gaps in the major stream vehicles are little and the occupation time of the turning movements increases significantly. This is believed to be due to the high mix-up of vehicles and weak or no lane discipline which leads to clustering of traffic. Sometimes even if conflicting flow is low, vehicles will experience more occupation time because of the

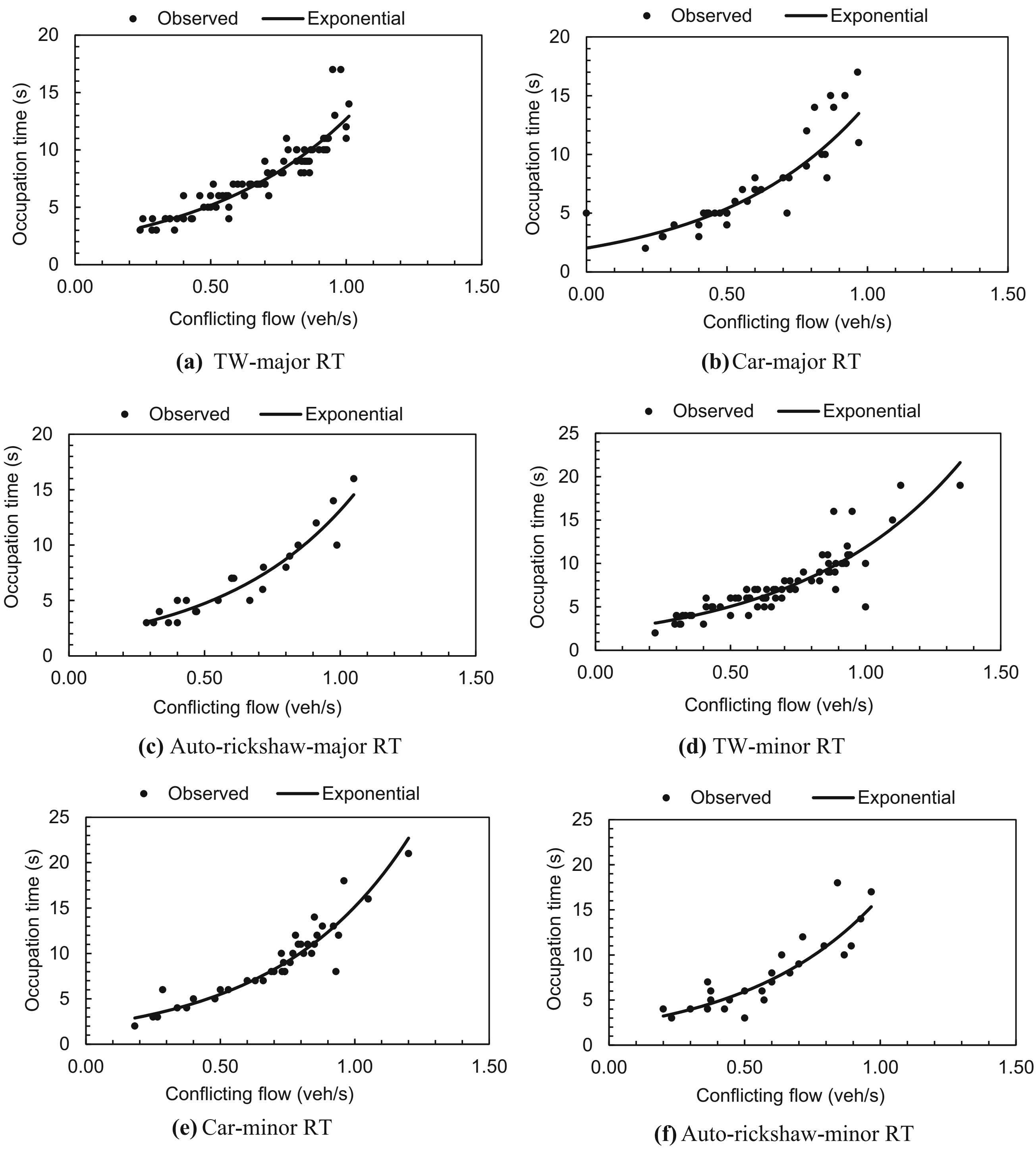


Fig. 7 Occupation time of vehicles at uncontrolled intersection

presence of heavy vehicles in the conflicting flow. If the heavy vehicles are at farther distance in the major road and also, there is enough gap for minor road vehicles to clear the conflict area, minor road vehicles will wait at the reference line till the HV clears the conflicting area.

To test the hypothesis that the occupation time does not depend on the type of vehicles, an analysis of variance (ANOVA) test was conducted. The null hypothesis was formulated as that means of occupation time of TWs, cars, and auto-rickshaws are equal. Table 5 gives the statistics for

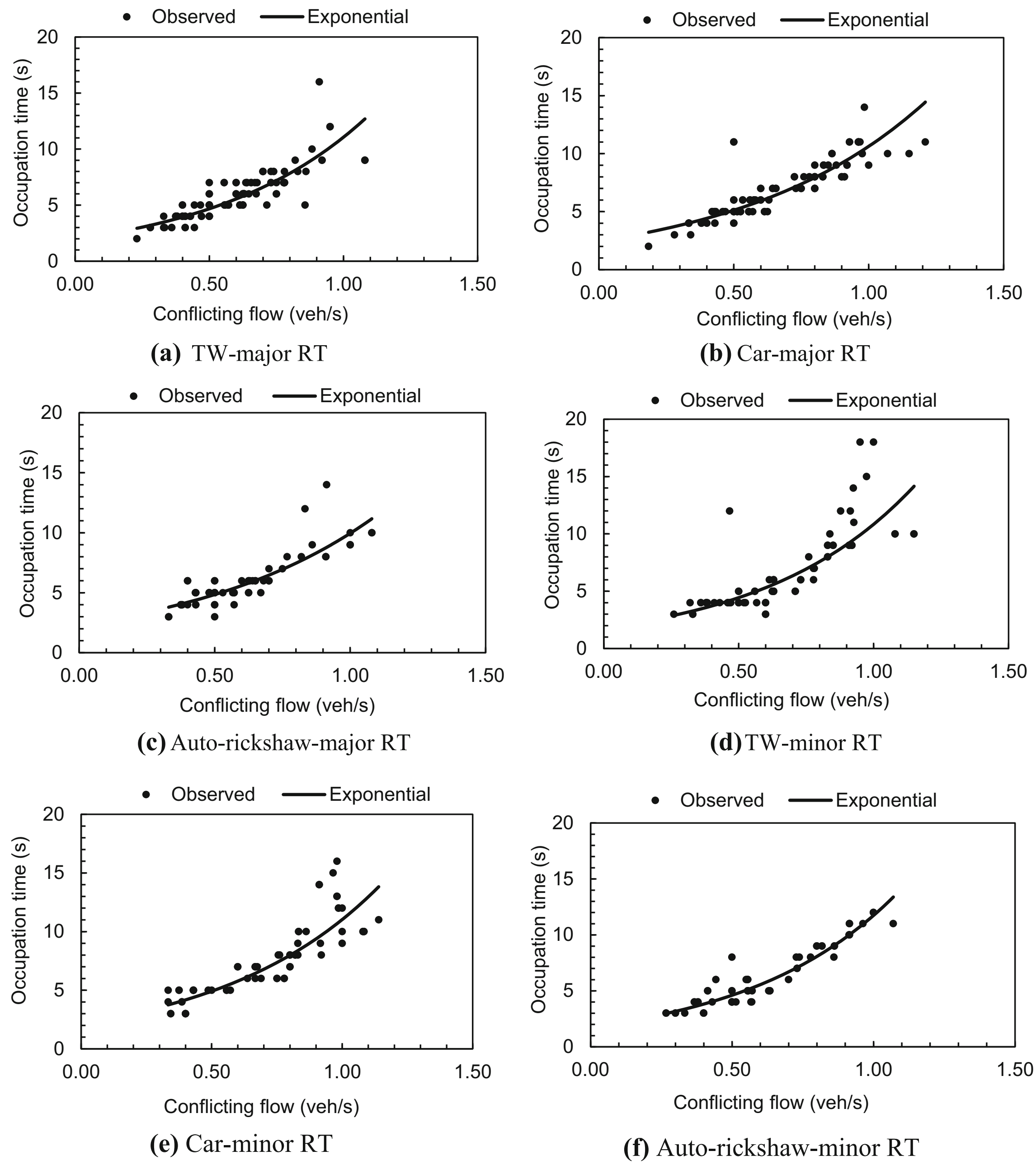


Fig. 8 Occupation time of vehicles at semicontrolled intersection

the ANOVA test for movements at Intersection A. In the case of major RT, the calculated value of F is less than the critical value, revealing that there is no significant difference between the means of occupation time of different types of vehicles. However, the null hypothesis is rejected in the case of minor RT, showing that the means of occupation time of different types of vehicles are statistically different. This may be due to the higher conflicting flow for this movement compared to major RT vehicles and also, may be due to the difference in the behavioral aspects of drivers. Similar tests were conducted at the other intersection also and found that the occupation time of major RT and minor RT vehicles do not depend on their types (Table 6). This may be explained from the reduction in the number of conflicting points at Intersection B due to partial segregation and the presence of mini roundabout. Hence, an aggregate model was also developed in addition to the relations for different types of vehicles (Tables 3 and 4).

Table 3 Mathematical equations fitted for each vehicle category at Intersection A

Type of movement	Subject vehicle	Occupation time equation	R^2 value
RT from major	TW	$t_o = 2.105e^{1.795V_{ct}}$	0.89
	Car	$t_o = 2.029e^{1.955V_{ct}}$	0.76
	Auto-rickshaw	$t_o = 1.704e^{2.024V_{ct}}$	0.90
	Aggregate model	$t_o = 2.021e^{1.869V_{ct}}$	0.84
RT from minor	TW	$t_o = 2.15e^{1.709V_{ct}}$	0.80
	Car	$t_o = 1.919e^{2.1V_{ct}}$	0.88
	Auto-rickshaw	$t_o = 2.157e^{2.028V_{ct}}$	0.78
	Aggregate model	$t_o = 2.116e^{1.856V_{ct}}$	0.79

Table 4 Mathematical equations fitted for each vehicle category at intersection B

Type of movement	Subject vehicle	Occupation time equation	R^2 value
RT from major	TW	$t_o = 2.929e^{1.768V_{ct}}$	0.75
	Car	$t_o = 1.485e^{2.38V_{ct}}$	0.81
	Auto-rickshaw	$t_o = 2.22e^{1.546V_{ct}}.$	74
	Aggregate model	$t_o = 2.174e^{1.593V_{ct}}.$	075
RT from minor	TW	$t_o = 1.757e^{1.892V_{ct}}.$	0.81
	Car	$t_o = 2.195e^{1.616V_{ct}}$	0.72
	Auto-rickshaw	$t_o = 1.832e^{1.842V_{ct}}.$	84
	Aggregate model	$t_o = 1.908e^{1.785V_{ct}}$	0.78

Table 5 Statistics of ANOVA test at Intersection A

Movement type	Vehicle types	F statistics		Inference
		Computed	Tabulated	
Major RT	TW, car, and auto-rickshaw	0.454	3.063	At $\alpha = 0.05$ and degrees of freedom (DOF) = 138, null hypothesis is accepted
Minor RT	TW, car, and auto-rickshaw	3.506	3.064	At $\alpha = 0.05$ and DOF = 135, null hypothesis is rejected

α is level of significance

Table 6 Statistics of ANOVA test at Intersection B

Movement type	Vehicle types	F statistics		Inference
		Computed	Tabulated	
Major RT	TW, car, and auto-rickshaw	2.63	3.05	At $\alpha = 0.05$ and DOF = 176, null hypothesis is accepted
Minor RT	TW, car, and auto-rickshaw	1.95	3.06	At $\alpha = 0.05$ and DOF = 128, null hypothesis is accepted

7 Conclusions

The present study aims to compare the occupation time observed at uncontrolled and semicontrolled intersections and to develop mathematical relations relating occupation time of different types of vehicles with conflicting flow rate. For this purpose, data were collected at three-legged uncontrolled intersections in Mangalore city, India using video graphic technique. At both the intersections, drivers do not follow the lane discipline and the rules of priority. These conditions have high impact on the occupation time of vehicles at unsignalized intersections. For each intersection, an aggregate occupation time model has been developed, to serve as a useful tool for performance evaluation of such intersections. The key conclusions arising out of this study were:

1. Models revealed that with an increase in the conflicting flow rate, the occupation time increases significantly. However, occupation time does not depend much on the type of vehicles.
2. On average, minor RT vehicles have higher occupation time than major RT vehicles. This is believed to be due to a larger number of conflicting flows.
3. Cars generally have higher occupation time compared to other types of vehicles at the intersections. This is because cars need more space to enter into the intersection and also, they have to wait for sufficient gap between the conflicting traffic.
4. TWs and auto-rickshaws generally experience less occupation time than other types of vehicles. This can be attributed to the smaller size and higher maneuver ability of TWs and the aggressive behavior and poor queue discipline of auto-rickshaws.
5. It was observed that for both major RT and minor RT, the semicontrolled intersection (Intersection B) has less occupation time than the uncontrolled intersection (Intersection A). The segregation of turning movements by partial control and the presence of mini roundabout at Intersection B can enhance maneuver ability of vehicles, but simultaneously increase the occupation time of straight through movements at Intersection B.

The proposed methodology will be useful to determine the occupation time for various movements at unsignalized intersections. The models developed in the study can be used by practitioners and traffic engineers to estimate the capacity of unsignalized intersections in non-lane-disciplined and mixed traffic conditions.

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